

# **SANDIA REPORT**

SAND2016-XXXX

Unlimited Unrestricted Release

Printed September 2016

## **Uncertainty quantification methodologies development for stress corrosion cracking of canister welds**

R. Dingreville, C.R. Bryan

Prepared by  
Sandia National Laboratories  
Albuquerque, New Mexico 87185 and Livermore, California 94550

Sandia National Laboratories is a multi-mission laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Approved for public release; further dissemination unlimited.



**Sandia National Laboratories**

Issued by Sandia National Laboratories, operated for the United States Department of Energy by Sandia Corporation.

**NOTICE:** This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government, nor any agency thereof, nor any of their employees, nor any of their contractors, subcontractors, or their employees, make any warranty, express or implied, or assume any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represent that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government, any agency thereof, or any of their contractors or subcontractors. The views and opinions expressed herein do not necessarily state or reflect those of the United States Government, any agency thereof, or any of their contractors.

Printed in the United States of America. This report has been reproduced directly from the best available copy.

Available to DOE and DOE contractors from  
U.S. Department of Energy  
Office of Scientific and Technical Information  
P.O. Box 62  
Oak Ridge, TN 37831

Telephone: (865) 576-8401  
Facsimile: (865) 576-5728  
E-Mail: [reports@adonis.osti.gov](mailto:reports@adonis.osti.gov)  
Online ordering: <http://www.osti.gov/bridge>

Available to the public from  
U.S. Department of Commerce  
National Technical Information Service  
5285 Port Royal Rd  
Springfield, VA 22161

Telephone: (800) 553-6847  
Facsimile: (703) 605-6900  
E-Mail: [orders@ntis.fedworld.gov](mailto:orders@ntis.fedworld.gov)  
Online ordering: <http://www.ntis.gov/help/ordermethods.asp?loc=7-4-0#online>



Uncertainty quantification methodologies development for stress  
corrosion cracking of canister welds

Rémi Dingreville  
Sandia National Laboratories  
Albuquerque, NM 87185  
rdingre@sandia.gov

Charles R. Bryan  
Sandia National Laboratories  
Albuquerque, NM 87185  
crbryan@sandia.gov

# Acknowledgments

This report documents a study funded by the Engineering Analysis Work Package under the Used Fuel Disposition Campaign (UFDC), Office of Nuclear Energy (DOE-NE). The authors would like to thank the UFD Engineering Analysis management team, Ken Sorenson, Sylvia Saltzstein and John Scaglione.

# Contents

<b>Nomenclature</b>	<b>7</b>
<b>Scope</b>	<b>9</b>
<b>Introduction</b>	<b>9</b>
<b>Criteria for SCC</b>	<b>10</b>
<b>General description of the probabilistic SCC model</b>	<b>10</b>
<b>Environment Model</b>	<b>11</b>
<b>Maximum pit size model</b>	<b>13</b>
<b>Pit-to-crack transition model</b>	<b>14</b>
<b>Crack growth rate model</b>	<b>15</b>
<b>Results and conclusion</b>	<b>16</b>
<b>References</b>	<b>17</b>

# List of Figures

1	General Timeline for SCC Initiation and Penetration of an Interim Storage Canister.	11
2	Canister surface temperature map, for a horizontal storage canister with a decay heat load of 7.6 kW. ....	12
3	Estimating maximum pit size using the approach described in [1]. ....	14

# Nomenclature

**10 CFR** Title 10 of the Code of Federal Regulations

**AH** Absolute humidity

**DOE** Department of Energy

**DRH** Deliquescence relative humidity

**DSC** Dry shielded canister

**EPRI** Electric Power Research Institute

**FEM** Finite element method

**FY** Fiscal year

**GWd/MTU** Gigawatt-days per metric tonne of uranium

**HAZ** Heated affected zone

**ISFSI** Interim spent fuel storage installation

**M&S** Modeling and simulation

**NE** Nuclear energy

**NOAA** National Oceanic and Atmospheric Administration

**NPP** Nuclear power plant

**NRC** Nuclear Regulatory Commission

**NUREG** US Nuclear Regulatory Commission Regulation

**PNNL** Pacific Northwest National Laboratory

**PWR** Pressured water reactor

**R&D** Research and Development

**RH** Relative humidity

**S&T** Storage and transportation

**SCC** Stress corrosion cracking

**SNF** Spent nuclear fuel

**SNL** Sandia National Laboratories

**SS** Stainless steel

**TWC** Through-wall crack

**UFD** Used fuel disposition

**UFDC** Used Fuel Disposition Campaign

**UNF** Used nuclear fuel

**UQ** Uncertainty quantification

**US** United States

**WRS** Weld residual stress



**This letter report documents the technical basis and results from the development of a probabilistic performance assessment model to evaluate the probability of canister failure (through-wall penetration) by stress corrosion cracking (SCC). The work conducted this fiscal year stems from the findings reported in “*Development of Uncertainty Quantification Methodologies as applied to Storage and Transportation R&D: Study on Stress Corrosion Cracking of Canister Welds*”, FCRD-UFD-2015-000127. Notably needs to better represent the environmental conditions at storage sites and to improve the physicality of the pitting initiation model have been identified. Improvement of these models have been the focus of this year work.**

## Scope

This letter report presents a probabilistic performance assessment model to evaluate the probability of canister failure (through-wall penetration) by SCC. The model first assesses whether environmental conditions for SCC – the presence of an aqueous film – are present at canister weld locations (where tensile stresses are likely to occur) on the canister surface. Geometry-specific storage system thermal models and weather data sets representative of U.S. spent nuclear fuel (SNF) storage sites are implemented to evaluate location-specific canister surface temperature and relative humidity (RH). As the canister cools and aqueous conditions become possible, the occurrence of corrosion is evaluated. Corrosion is modeled as a two-step process: first, pitting is initiated, and the extent and depth of pitting is a function of the chloride surface load and the environmental conditions (temperature and RH). Second, as corrosion penetration increases, the pit eventually transitions to a SCC crack, with crack initiation becoming more likely with increasing pit depth. Once pits convert to cracks, a crack growth model is implemented. The SCC growth model includes rate dependencies on both temperature and crack tip stress intensity factor, and crack growth only occurs in time steps when aqueous conditions are predicted. The model suggests that SCC is likely to occur over potential SNF interim storage intervals; however, this result is based on many modeling assumptions. Sensitivity analyses provide information on the model assumptions and parameter values that have the greatest impact on predicted storage canister performance, and provide guidance for further research to reduce uncertainties.

## Introduction

Following initial cooling in pools, spent nuclear fuel (SNF) is transferred to dry storage casks for longer-term storage at the reactor sites. The storage cask systems are commonly welded stainless steel containers enclosed in ventilated concrete or steel overpacks. These cask systems are intended as interim storage until a permanent disposal site is developed, and until recently, were licensed for up to 20 years, and renewals also up to 20 years. In 2011, 10 CFR 72.42(a) was modified to allow for initial license periods of up to 40 years, and also, license extensions of up to 40 years. However, the United States does not currently have a disposal pathway for SNF, and these containers may be required to perform their waste isolation function for many decades beyond their original design

criteria. Of primary concern with respect to the long-term performance of the storage casks is the potential for canister failure due to localized corrosion. For most dry cask storage systems, passive ventilation is utilized to cool the casks within the overpacks, and large volumes of outside air are drawn through the system. Dust and aerosols within the air are deposited on the steel canisters, and as the casks cool over time, salts in the dust will deliquesce to form brine on the storage container surface. Under these conditions, chloride-induced stress corrosion cracking (SCC) of welded zones is of concern, as it is a well-documented mode of attack for austenitic stainless steels in marine environments [6], and many independent spent fuel storage installations (ISFSIs) are located in coastal areas. Recent canister inspections have shown that chloride salts can be present on the surface of in-service canisters in near-marine settings [2, 12]. Here, the available information on the canister surface environment and experimental and observational experience with stress corrosion cracking of stainless steels is utilized to develop a probabilistically-based model for evaluating the potential for SNF interim storage canister failure by through-wall SCC.

## Criteria for SCC

In order for SCC to occur, three criteria must be met:

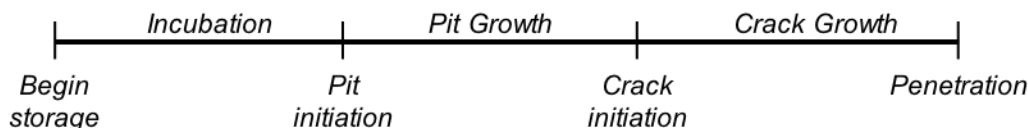
1. the metal must be susceptible to SCC,
2. an aggressive environment must exist,
3. and sufficient tensile stress must be present to support SCC.

In general, these criteria are expected to be met, at least at some ISFSI sites, during the period of interim storage, especially if the development of a repository for final disposal is delayed. The welded interim storage canisters are made of austenitic stainless steels which are susceptible to SCC, especially in the heat affected zones (HAZ) of welds. Field studies have found chloride salts on the canister surfaces at some sites; if temperatures drop sufficiently for salt deliquescence, a corrosive aqueous environment could potentially occur. Finally, recent weld residual stress (WRS) modeling conducted by the Nuclear Regulatory Commission (NRC) [8] indicates that through-wall tensile stresses of sufficient magnitude to support SCC are likely to exist in weld HAZ; these predictions have been confirmed by recent measurements of WRS on a full-diameter mockup funded by the U.S. DOE [3].

## General description of the probabilistic SCC model

The general progression of conditions leading to canister penetration by SCC is shown in Fig. 1. Each of these mechanisms and associated characteristics time constants are incorporated into the model described here. After placement into storage, the evolution of the canister surface environment (temperature, relative humidity, and salt load) is tracked through time. First, there is an

incubation period for pitting, corresponding to the interval of time required for a given canister surface location to cool to the point that the relative humidity (RH) is sufficiently high for salts to deliquesce and corrosion becomes possible. This limiting RH value for corrosion is known as RHL. The incubation period is calculated using an environmental model that combines a canister surface temperature model with ambient weather data to calculate whether the RHL has been exceeded in each time step. Once the RHL is reached, a maximum pit size model is used to evaluate the deepest pit that can be on the surface, as a function of the canister surface environment. Over time, as the canister cools and the deposited salt load increases, the maximum pit size increases. Pits are required precursors for stress corrosion cracks, and the likelihood of SCC initiation from a pit increases as the pit deepens [11]. A pit-to-crack transition model is used to evaluate when a crack initiates. The crack growth rate is then calculated as a function of temperature and through-wall stress profile, and applied to the crack for any time-steps when aqueous conditions are predicted to occur (a time-of-wetness model). For each simulation in the probabilistic model, this calculation is done at all locations on the canister surface that correspond to weld locations. Each realization is run for either 100 years or until crack penetration is predicted. The probabilistic results are determined from 100 total realizations, each with a different sampled set of parameter values.



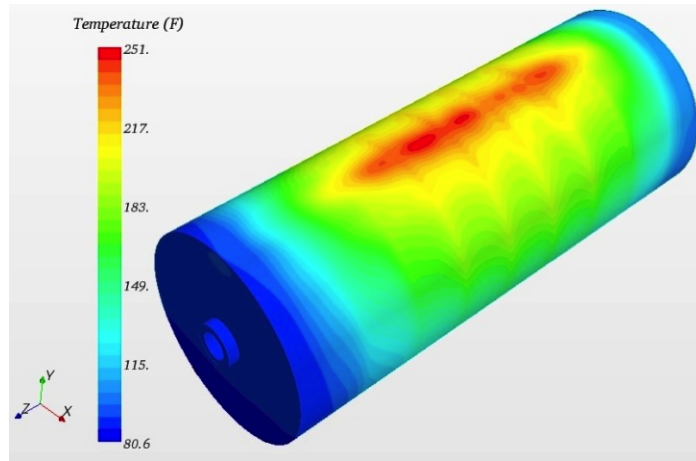
**Figure 1.** General Timeline for SCC Initiation and Penetration of an Interim Storage Canister.

## Environment Model

The environment at any given location on the storage canister surface will be aggressive if two criteria are met:

1. a corrosive chemical species is present,
2. and aqueous conditions exist.

The geographic location of the storage facility impacts the composition of dust, with coastal sites containing higher amounts of chloride-bearing sea-salts [5] and ammonium salts [4]. Inland sites are impacted by local soil and geology; containing higher levels of silicate, aluminosilicate, carbonate materials, ammonium, sulfate, and nitrates. As the temperature and relative humidity fluctuate



**Figure 2.** Canister surface temperature map, for a horizontal storage canister with a decay heat load of 7.6 kW.

at a site, components of the deposited dust can dissolve in absorbed moisture (deliquescence). The dissolved ions are then available to participate in corrosion of the canister.

The greatest concern of SCC is at near-marine sites, so the assumption is made in this model that the deposited salts are chloride-rich sea-salts. Deposition of chloride-rich salts is assumed to begin immediately upon emplacement, and the deposited surface load increases over time. Some amount of chloride is always assumed to be present; therefore, in this model, corrosion can occur, or progress, at any location the canister surface where the time-step-specific RH is greater than the RHL. The location-specific RH values can be calculated from the canister surface temperature at any given location; and the absolute humidity (AH), or water content, of the inflowing air. To determine location-specific canister surface temperatures through time, maps of canister surface temperatures were calculated using a specific set of values for horizontal and vertical storage system designs, using specific fuel loadings (number and geometry of assemblies); fuel burnup; heat load (corresponding to a given time out of reactor), and a single fixed ambient external temperature. The parameter values used are described elsewhere [10]. The thermal modeling provided temperature maps of the canister surface (for example, Fig. 2) for each of 8 decay heat loads corresponding to different lengths of time out of the reactor, for a single ambient temperature of 15.6°C (60°F). For each time step in the 100-year simulation, the temperature predicted by the thermal model is modified for the actual ambient temperature, sampled from measured weather data corresponding to an existing ISFSI site.

Similarly to the ambient temperature, the predicted absolute humidity (AH) was sampled from a model based on measured weather data. Given the location-specific temperature and the AH of the incoming air, the RH at any point on the surface of the canister can be calculated, and is compared to the RHL to determine if corrosion is possible.

## Maximum pit size model

The maximum pit size that can form on the metal surface is calculated using an approach developed by Chen and Kelly [1]. This model describes the maximum pit depth as a function of several environmental parameters. In order for a pit to undergo stable growth, the cathode current ( $I_c$ ) available to support pit growth must exceed the anodic current ( $I_{pit}$ ) demand for the pit. The maximum pit size can then be calculated by calculating the maximum cathode current as a function of pit size, and comparing it to the predicted anodic current demand as a function of pit size. The ability of the cathode to supply current to the anode is controlled by the thickness and ionic strength of the brine layer on the metal surface. To calculate ( $I_c$ ) and ( $I_{pit}$ ), it is assumed [1] that the pit is hemispherical in shape with a radius of  $r_{pit}$ . The pit can grow stably when the value of  $I_{pit}/r_{pit}$  exceeds a critical value, called the pit stability criterion. By assuming a given value for the pit stability criterion,  $I_{pit}$  can be calculated as a function of the pit radius.

$$\ln(I_{c,max}) = \frac{4\pi kW_L \Delta E_{max}}{I_{c,max}} + \ln \left( \frac{\pi e r_a^2 \int_{E_{corr}}^{E_{rp}} [I_c - I_p] dE}{\Delta E_{max}} \right), \quad (1)$$

where,

$k$  – conductivity,  $m^{-1}.\Omega^{-1}$

$W_L$  – brine layer thickness, m

$I_c$  – cathodic current density,  $A/m^2$

$I_p$  – passive current density,  $A/m^2$  (assumed to be  $10^{-4}$   $A/m^2$  in [1])

$E_{rp}$  – repassivation potential = -0.4  $V_{SCE}$  in [1] for 304 = potential at the mouth of the pit

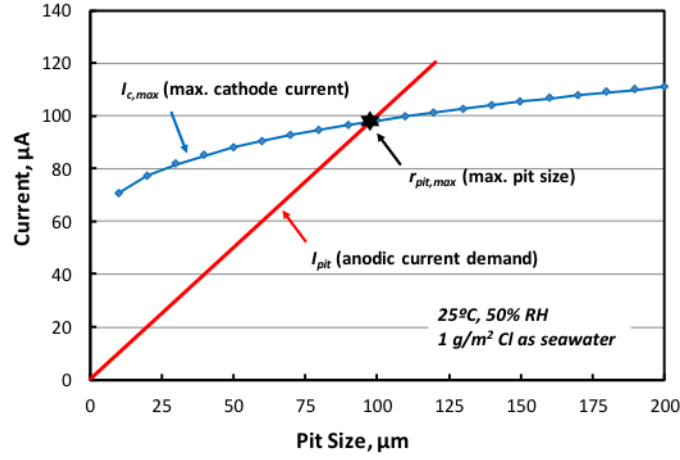
$E_{corr}$  – -0.15  $V_{SCE}$  in Chen and Kelly =  $E_L$  = potential at the cathode edge

$e$  – Euler's number 2.71828

$r_a$  – pit radius, m

$\Delta E_{max}$  – potential difference  $E_{corr} - E_{rp}$ , V

Derivation of the values for these parameters is describe in [1] and in subsequent papers by these authors [9, 13, 14]. Several of the parameters vary with the environmental conditions on the canister surface (temperature, RH, and salt load), including the conductivity  $k$ , the brine thickness  $W_L$ , and the integral term on the right hand side of the equation, which is derived from a cathodic polarization scan of the metal of interest (304 SS) in the brine of interest. Utilizing the environmental model described above, and assuming a salt deposition rate, a maximum pit size can be calculated at a given location on the canister surface at each time step as shown in Fig. 3. The maximum cathode current for a given pit size is calculated using the equation above, and the anodic current from the pit stability criterion. The maximum possible pit size corresponds to size at which these two values are equivalent.



**Figure 3.** Estimating maximum pit size using the approach described in [1].

## Pit-to-crack transition model

Once the pit reaches a threshold value, a stress corrosion crack initiates. The threshold value is calculated using the Kondo criterion [7]; the crack tip stress intensity factor ( $K$ ) is calculated for a crack of equivalent depth as the pit, and a crack will initiate if the calculated  $K$ -value exceeds the threshold  $K$  for SCC,  $K_{ISCC}$ . In the probabilistic SCC model,  $K$  is calculated as a function of depth using data from tensile stress profiles for longitudinal and circumferential welds that were modeled by the NRC [8], and the  $K_{ISCC}$  threshold value is sampled once per realization from a range of literature values.

Although this approach is simplified, this combination of the maximum pit depth model and the pit-to-crack transition model provides insights into the process of SCC crack initiation. Implicit in this model is that conditions that produce thicker brine layers, such as heavy salt loads, or moderate increases in RH, increase the size of possible pits that can form, and increase the likelihood of SCC initiation. Also, higher tensile stresses mean that the  $K$  value increases more rapidly with depth, and hence shallower pits can initiate SCC. These predictions match what has been observed experimentally [8]. Moreover, failure to evaluate salt load, RH and stress level independently may explain the variability in measured RH thresholds and chloride surface load thresholds for SCC initiation. The type of salt used can also have a huge impact. Below a RH of about 75% on the canister surface, a large fraction of the chloride in sea-salts may be present in the solid form. For instance, at 60% RH, sea-salts are only partially deliquesced?most chloride is present in as precipitated salts. For a chloride deposition load of  $1 \text{ g.m}^{-2}$ , the total brine present corresponds to a layer less than 1 micron thick. On the other hand, if the chloride is deposited as magnesium chloride, then at 60% RH, a  $1 \text{ g.m}^{-2}$  chloride load produces a brine layer over 300 microns thick. This thicker brine layer corresponds to a much larger cathode, a larger potential cathode current,

and much deeper pits. Because of this difference, magnesium chloride is a poor analog for sea-salts, unless it is applied much more sparingly to the surface.

## Crack growth rate model

Once a crack initiates, a crack growth rate is calculated every time step, and applied if the environmental model indicates that aqueous conditions are present. That is, the magnitude of the crack growth is a function of both the rate of growth and the time-of-wetness. SCC crack growth rates can be expressed in the following general form:

$$\frac{x_{\text{crack}}}{dt} = \alpha_{\text{crack}} f_1(T) f_2(K) f_3(R_a) f_4([\text{Cl}^-]) f_5(\text{pH}) f_6(\sigma_y) , \quad (2)$$

where  $\alpha_{\text{crack}}$  is the crack growth amplitude factor (or, the crack growth rate at a fixed reference set of conditions), and that value can be modified by many other factors, including material property factors such as the stress intensity factor ( $K$ ), degree of sensitization ( $R_a$ ), and the yield stress  $\sigma_y$ ; and environmental factors such as temperature ( $T$ ), chloride concentration ( $[\text{Cl}^-]$ ), the mass of chloride per unit surface area, and the solution pH.

The effects of  $K$  and  $T$  are included in the model presented here; the other factors are not considered explicitly, but are included implicitly in the experimental data sets used to parameterize the SCC growth rate. The experimental data sets include base metal, weld, HAZ, and sensitized samples, and both 304 and 304L, capturing the effects of different  $R_a$  and  $\sigma_y$  values. For a model accounting only for the effects of  $K$  and  $T$ , a power law dependence is assumed for  $K$ , while an Arrhenius relationship is assumed for the temperature dependence [15]:

$$\frac{x_{\text{crack}}}{dt} = \alpha_{\text{crack}} \exp \left( -\frac{Q}{R} \left[ \frac{1}{T} - \frac{1}{T_{\text{ref}}} \right] \right) (K - K_{th})^{\beta_{\text{crack}}} \quad (3)$$

where

$dx_{\text{crack}}/dt$  – crack growth rate

$\alpha_{\text{crack}}$  – crack growth amplitude

$Q$  – cathodic current density, A/m<sup>2</sup>

$R$  – universal gas constant (8.314 J mol<sup>-1</sup>.K<sup>-1</sup>)

$T$  – temperature, K

$T_{\text{ref}}$  – reference temperature (K) at which was derived. To be consistent with the PNNL thermal model, a reference temperature of 15.55°C (60°F) is used as the reference temperature.

$K$  – crack tip stress intensity factor

$K_{th}$  – threshold stress for SCC

$\beta_{\text{crack}}$  – stress intensity factor exponent

The above equation is implemented in this report. For a cracked structure under remote or local loads, the stress intensity factor (K) is a measure of the stress field ahead of the crack. The stress intensity factor  $K = \sigma_{\text{applied}} Y \sqrt{\pi x_{\text{crack}}}$ , where  $\sigma_{\text{applied}}$  is the tensile stress from the weld residual stress profile and  $Y$  is a shape parameter, equal to 1 for an infinite flat plate. The threshold stress intensity factor for SCC,  $K_{th}$ , was sampled from a range of literature values for each realization. The stress corrosion cracking growth rate model is parameterized by fitting experimental rates determined for atmospheric SCC under ambient and high temperature conditions for 304 and 304L stainless steels, from several literature sources.

## Results and conclusion

Due to timing and budget restrictions, the model for SCC prediction presented here has not been completely parameterized. Specifically, more data are needed to parameterize the maximum pit size model, including cathodic polarization curves for brine compositions typical of deliquesced sea-salts. The model has not yet been used to estimate canister penetration times. However, in developing the model, the importance of certain parameters has become clear. Parameters controlling the incubation time are for SCC include the RH and the salt load on the canister surface, which will determine when a pit can grow to sufficient size to initiate from a crack. Once a crack initiates, the sampled crack growth rate is the most important parameter affecting predicted breakthrough times, largely because of the high scatter in the available data used to parameterize the model.

**Although the model still lacks some parameterization, the model conceptualization offers insights into the factors controlling canister penetration by SCC, and highlights research needs to reduce the scatter. simplified, the basic approach has been developed and applied to an example case. The study illustrates the need for additional experimental efforts to allow quantitative evaluation of important processes (e.g., pit initiation and growth under atmospheric conditions), and to reduce uncertainties in important parameters such as SCC growth rate, limiting RH for corrosion, and weld residual stress profiles. Additional model development and parameterization is required prior to applying it to SNF canisters at actual ISFI sites.**



# References

- [1] Z.Y. Chen and R.G. Kelly. Computational modeling of bounding conditions for pit size on stainless steel in atmospheric environments. *Journal of The Electrochemical Society*, 157(2):C69–C78, 2010.
- [2] Bryan C.R. and Enos D.G. Analysis of dust samples collected from spent nuclear fuel interim storage containers at Hope Creek, Delaware, and Diablo Canyon, California. SAND 2014-16383, Sandia National Laboratories, 2014.
- [3] Enos D.G. and Bryan C.R. Understanding the risk of chloride induced stress corrosion cracking of interim storage containers for the dry storage of spent nuclear fuel: Residual stresses in typical welded containers. Corrosion:NACE International, 2016.
- [4] D.G. Enos, C.R. Bryan, and K.M. Norman. Data report on corrosion testing of stainless steel SNF storage canisters. FCRD-USED- 2013-000324, SAND2013-8314P, Fuel Cycle Research & Development. Used Fuel Disposition Campaign., 2013.
- [5] G. Gordon, M. Taylor, and A. Deardorff. Effects of marine environments on stress corrosion cracking of austenitic stainless steels. Technical update 1011820, Electric Power Research Institute (EPRI), Palo Alto, CA, 2005.
- [6] R.M. Kain. Marine atmosphere corrosion cracking of austenitic stainless steels. *Materials Performance*, 29:60–62, 1990.
- [7] Y. Kondo. Prediction of fatigue crack initiation life based on pit growth. *Corrosion*, 45(1):7–11, 1989.
- [8] J. Kusnick, M. Benson, and S. Lyons. Finite element analysis of weld residual stresses in austenitic stainless steel dry cask storage system canisters. Technical Letter Report ML13330A512, U.S. Nuclear Regulatory Commission, Washington D.C., 2013.
- [9] J Srinivasan, MJ McGrath, and RG Kelly. A high-throughput artificial pit technique to measure kinetic parameters for pitting stability. *Journal of The Electrochemical Society*, 162(14):C725–C731, 2015.
- [10] J.M. Suffield, S. R.Cuta, J.A. Fort, B.A. Collins, H.E. Adkins, and E.R. Siciliano. Thermal modeling of NUHOMS HSM-15 and HSM-1 storage modules at Calvert Cliffs nuclear power station ISFSI. PNNL- 21788, Pacific Northwest National Laboratory, Richland, WA, 2012.
- [11] A. Turnbull, L.N. McCartney, and S. Zhou. A model to predict the evolution of pitting corrosion and the pit-to-crack transition incorporating statistically distributed input parameters. *Corrosion Science*, 48(8):2084–2105, 2006.

- [12] K. Waldrop, W. Bracey, K. Morris, C. Bryan, and D. Enos. Calvert Cliffs stainless steel dry storage canister inspection. Technical report 1025209, Electric Power Research Institute (EPRI), Palo Alto, CA, 2014.
- [13] M.T. Woldemedhin, M.E. Shedd, and R.G. Kelly. Evaluation of the maximum pit size model on stainless steels under thin film electrolyte conditions. *Journal of The Electrochemical Society*, 161(8):E3216–E3224, 2014.
- [14] MT Woldemedhin, J Srinivasan, and RG Kelly. Effects of environmental factors on key kinetic parameters relevant to pitting corrosion. *Journal of Solid State Electrochemistry*, 19(12):3449–3461, 2015.
- [15] G. Wu and M. Modarres. A probabilistic-mechanistic approach to modeling stress corrosion cracking in alloy 600 components with applications. *PSAM*, 2012.



